THE ORE-DEPOSITS OF BORAH CREEK, NEW ENGLAND DISTRICT, N.S.W.

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(Plates xv.-xvi.)

CONTENTS.

INTRODUCTION.

In June and July, 1909, it was my good fortune to visit the Conrad Stannite Mine at Borah Creek. The Manager, Mr. L. Judell, made my stay a very pleasant one, and afforded me every facility for investigating the mine throughout the greater part of the workings. Unfortunately mining operations were suspended at the time of my visit; and though the water was being kept out of the main drive, the bottom level was still under water and could not be examined. It is my desire to record here my great appreciation of Mr. Judell's kindness and help in assisting me to an understanding of the mine and its workings.

[The mine was again visited in May, 1910. It was then under the management of Mr. Beasley, to whom, as well as to Mr. J. F. Stephen, I am indebted for the information obtained during this second visit.]

The Conrad Stannite Mine is situated on Borah Creek, at Howell, about 18 miles south by west from Inverell. It may be

reached from the latter town either by the Inverell-Copeton Road, or by a turn-off from the Inverell-Bundara Road. The country in the immediate vicinity of Howell presents some very interesting physiographic features. The New England Plateau is here worn to the level of the Stannifer* peneplain, above which residuals of an older peneplain about 400 feet higher are visible. This plateau is intersected by the Gwydir River, of which Borah Creek is a tributary.

The country-rock is one of the "acid granites,"† and is of a reddish colour on account of the abundant pink orthoclase crystals present. Comparatively large areas, several acres in extent, of smooth bare granite relieve the forest-greens by their brick-red colour. This is specially noticeable on the northern slopes of the hill facing the town. The Borah Creek Lode has proved of less hardness than the "acid granite," and its consequent more rapid rate of erosion has determined the position of the creek, which follows the outcrop in a most marked manner (see text-fig.1). The lode has been intersected by one conspicuous fault which has thrown it, and has also left its mark upon the topography. Where the fault crosses the lode in Borah Creek, a small tributary is developed on each side along the line of the fault-plane (see text-figs.1-2).

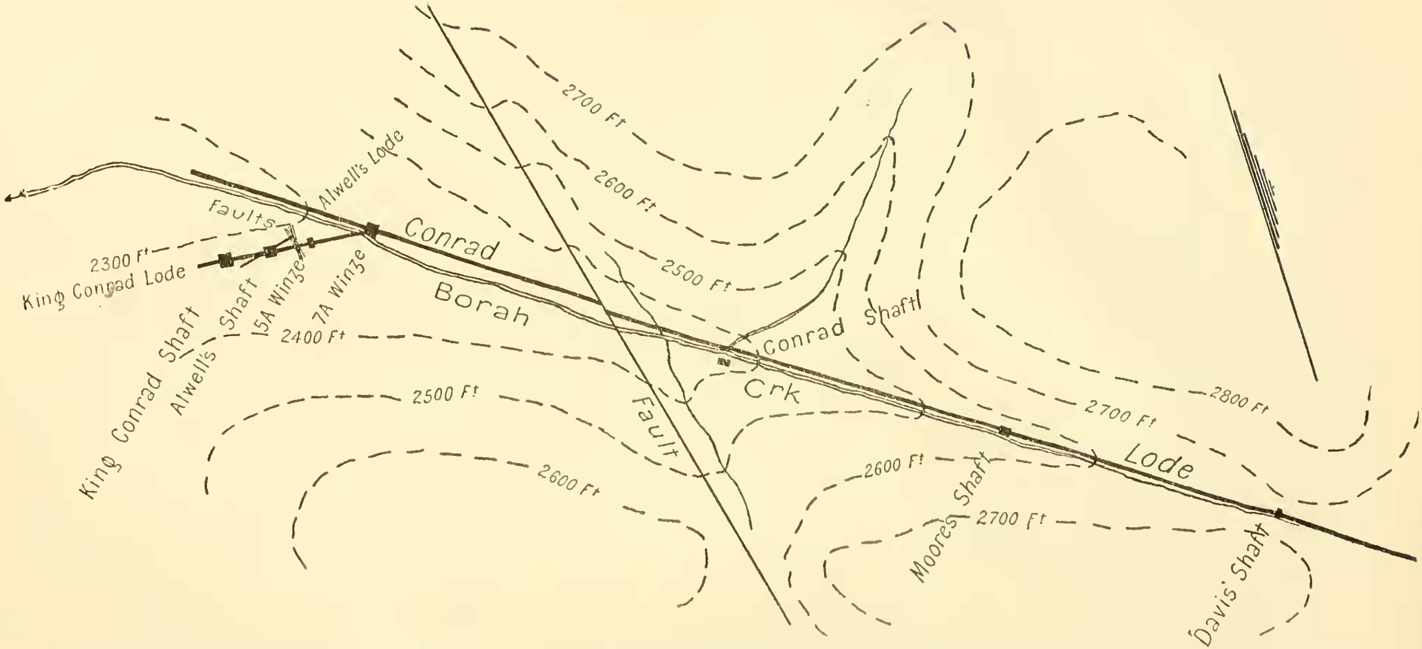
Geology.

The geological formations of the district consist of three units, slates, granites, and basalts.

The slates are the oldest series, and are probably of Silurian age. They are everywhere much altered by the intrusions of the later granites. The nearest occurrence of these rocks to the mine is a comparatively small patch, situated about 2 miles to the north by east from Howell.

* Andrews, E. C., "The Geology of the New England Plateau. Part i., Physiography." Records Geol. Survey N.S.Wales, Vol.vii., pp.281, 1904.

† *Ibid.*, Parts ii. and iii., with special reference to the granites of Northern New England.



Text-fig. 1.—Plan of Borah Creek silver-lodes, illustrating relations of the lodes to Borah Creek, and also the influence of the main fault on the physiography, as indicated by the sketch-contours.

The basalts are the youngest formations, and, like the clay-stones, do not occur closer than a mile or thereabouts to the mine. Even at this distance there is no great development of basalt, the occurrence being of the nature of cappings to Tertiary leads. The basalts themselves have been clearly demonstrated to belong to the Tertiary period.

It is with *the granites* that the ore-deposits are concerned; and of these granites there are two main types. The most important in this discussion is the "acid granite," previously mentioned; and the other has been designated, by me, the Tingha Granite. The latter is certainly the older rock, and has been intruded by the "acid granite." It is a hornblende-biotite granite, with large porphyritic crystals of plagioclase felspar. The "acid granite" consists almost entirely of quartz and felspar in its type development. Various phases of it contain small proportions of biotite, and tourmaline is occasionally present. Micrographic intergrowth of quartz and felspar is a very characteristic feature.

A small part of the generalised map of the district (see text-fig.3) given in a former paper* is reproduced to show the approximate relationships of the geological units in the vicinity of the mine. The boundaries here have not been traversed, and are only crude approximations; yet they are sufficiently accurate for the purposes of this discussion.

Ore-Deposits.

It will be seen, by reference to the map, that the ore-deposit at Borah Creek occurs in a tongue of "acid granite," at no great distance from the contact formed by its intrusion into the Tingha Granite; indeed the south-eastern portion of the ore-deposit crosses the junction of the granites. The lode, though readily traceable on the surface for over two miles, has, for such a permanent ore-body, quite an insignificant outcrop. Towards its north-western limit the main lode is joined by another, known

* Cotton, Leo A., "The Tin-Deposits of New England, N.S.W. Part i. The Elsmore-Tingha District." Proc. Linn. Soc. N.S.Wales, 1909, p.733.

as the King Conrad Lode. The main lode has now been prospected for more than a mile in length, and the ore-values have proved fairly uniform over that distance. Shoots of ore do occur, but these will be considered later. The main drive in the mine is at the 400-feet level from the King Conrad shaft, and this is connected right through to the Conrad shaft, about half a mile to the south-west. Several shafts have been sunk on the lode, and these may be seen by reference to text-fig.2. As the lode outcrops on the summit of the hill, about 400 feet above the King Conrad Mine; and as the deepest level is the 550 feet drive from the bottom of Moore's shaft, the vertical extent of the ore-body has been proved for about 1000 feet.

The chief minerals present are quartz, galena, sphalerite, arsenopyrite, pyrite, chalcopyrite, and stannite. The combination of these makes the ore a very refractory one; and the metallurgical problem has, so far, been the stumbling block in the development of the mine.

The fracture system of the district is worthy of some consideration, as it enables the relative age of the ore-body to be determined. Observations of joint-systems show that the following directions of jointing are represented within two miles of the mine. The bearings are given in degrees, measured clockwise from north, which is taken as the zero-position.

25°, 43°, 92°, 103°, and 355°.

A comparison of these directions with those prevalent in the Elsmore-Tingha tin-bearing area,* some 10 miles to the east, shows that they may all be grouped in the representative systems of that district. The bearing of the King Conrad Lode is 98°, and that of Alwell's lode is 85°. These both correspond to known fracture-systems of the area just mentioned. The main Conrad Lode, however, bears 125°, and does not correspond to any of the important systems of fracture above referred to. This lode, moreover, is thrown by a fault bearing N.15°W., which direction has no representative in the Elsmore-Tingha District.

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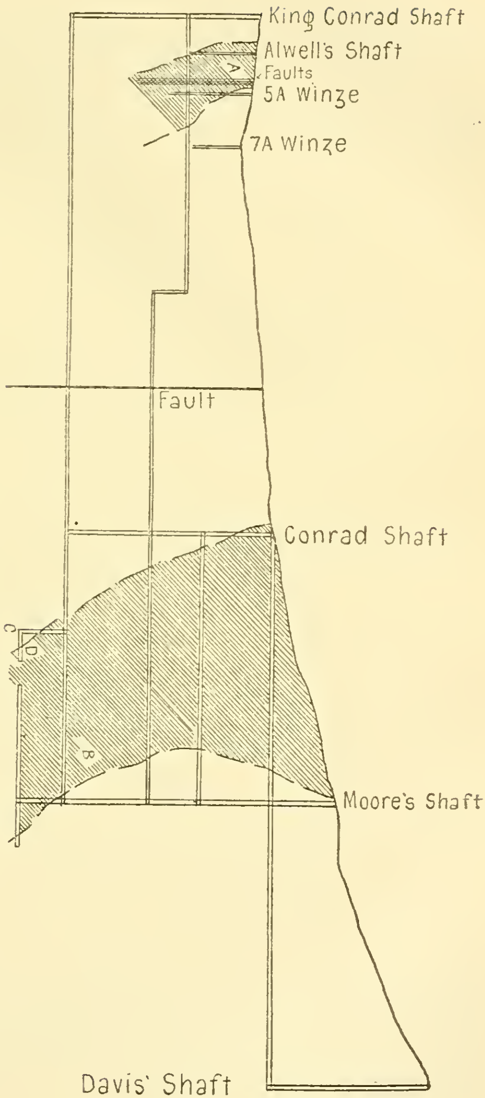
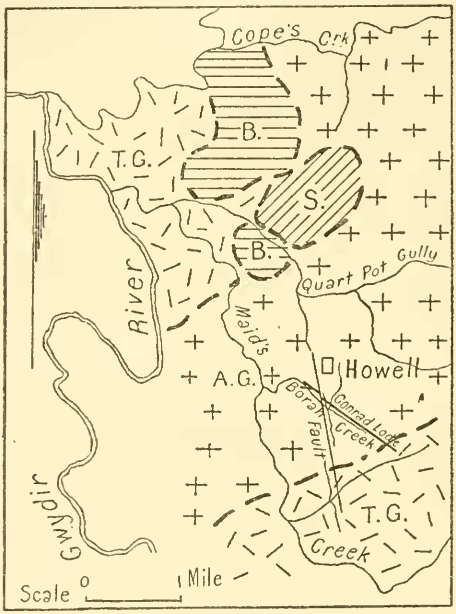
* Cotton, *loc. cit.*, p.752.



Text-fig. 2.—Section of the Borah Creek silver-lodes, showing the positions of the two chief ore-shoots by the shaded areas.

At A, metasomatic replacement of galena by quartz—At B, metasomatic replacement of quartz by sphalerite—At C, winze connecting 400 and 550 ft. levels—At D, ascending waters met with in drive.

From this it would appear, that the main Conrad Lode and the large fault which intersects it, are younger than the Elsmore-Tingha system of fractures; for it is difficult to imagine how such a large and permanent fissure could have escaped alteration during the epoch of formation of cassiterite veins. The fault referred to is, in the main, due to horizontal strain. The fault-



Text-fig. 3.—Illustrating the relation of the lodes to the geology of the district.

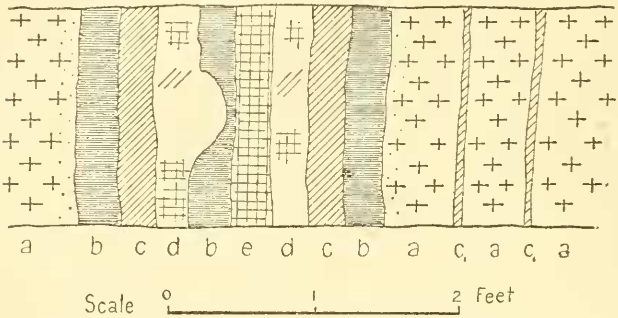
T.G., Tingha Granite—A.G., Acid Granite—B., Basalt—S., Slate.

plane is nearly vertical, hading slightly to the west; and the horizontal displacement of the lode, which is itself practically vertical, amounts to about 15 feet. It is probable that the fissure was formed to relieve the strain due to the final stages in the cooling of the granite-stock.

The Lodes.

The King Conrad Lode has been mentioned as a fissure joining the main Conrad Lode from the south-west side. The main shaft was sunk on the north side of the lode to a depth of 400 feet, and the lode was then worked by a main drive from this level, which was carried on to the Conrad Lode. There was no indication that the King Conrad Lode crossed the Conrad Lode, and work has not been carried on beyond the latter ore-body. Another level has been driven at 150 feet, and most of the good ore has now been stoped above this level. The lode is narrow, varying from about 9 inches up to 3 feet in thickness; the average width is about 18 inches. The lode-material consists of quartz, pyrite, arsenopyrite, argentiferous galena, sphalerite, chalcopyrite, and stannite. The last of these was not observed in any portion of the lode visited by me, but the Manager informs me that its presence is revealed by analyses. The fissure is a clean break, and the lode is exceptionally free from brecciated masses in the lode-material. Near its junction with the Conrad Lode there is, however, a large lens of granite at the 400-feet level. The lode abuts sharply against the granite-walls, which have not been impregnated with mineral to any extent. There is no soft casing or "dig" to the lode, but the ore-body is "frozen" to the walls. An excellent section of the lode at the 150-feet level was sketched from a fresh fracture (see text-fig.4). The ore-body here consisted of a solid mineral mass about 2 feet wide, and a couple of small veins each about an inch wide, running parallel to the main mass. The three outer layers of mineral are symmetrically disposed on each side of the lode, while the two central bands destroy the symmetry of the whole. Arsenopyrite, as a solid crystalline mass, occupies the outermost zone; next comes a band of sphalerite and chalcopyrite; and the third zone is a band of milk-white, crystallised quartz, which towards its outer margin, is intergrown with argentiferous galena. The central portion of the vein is filled by two bands of mineral, one of arsenopyrite and the other of argentiferous galena.

A noticeable feature of the lode is that there is practically no zone of oxidation, the sulphides being found right at the surface. What little oxidised ore does exist, occurs on the slope of the hill near Moore's and Davis' shafts, and extends only to a depth of 30 feet. A very interesting example of metasomatic replacement of galena by quartz is to be seen in one of the upper stopes. Here the crystallised galena can be traced gradually into pure quartz. The quartz has retained the cleavages of galena to perfection. Samples of the latter, in thin seams between flat sheets



Text-fig. 4.—Section of King Conrad Lode, illustrating sequence of the ore-deposition.

a, granite slightly altered next the lode—*b*, arsenopyrite—*c*, sphalerite and chalcopyrite—*d*, quartz intergrown with argentiferous galena and sphalerite—*e*, argentiferous galena—c_1 small banded veins, chiefly sphalerite and galena.

The Conrad Lode.

of quartz, may be observed where the replacement is not quite complete. The replacement has been effected by surface-waters. It is worthy of note that this metasomatic action has taken place in the main ore-shoot of the King Conrad Lode. A glance at text-fig.2 shows the position (marked A) with reference to the ore-shoot, which may be seen as an irregularly shaped mass pitching easterly.

The Conrad Lode is undoubtedly the main ore-body; it persists for considerably more than a mile in length, and has been

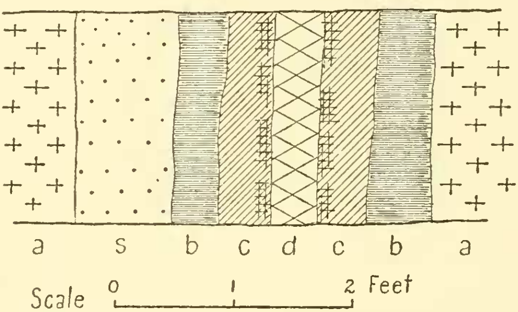
prospected for over 6000 feet along the line of outcrop. The latest figures show that the mine has been worked continuously for more than 4000 feet along the lode. North of its junction with the King Conrad Lode the outcrop is not so well marked, but two prospecting shafts sunk along the line of lode have both shown ore-values. The lode has been mainly worked between the King Conrad and the Conrad Shafts. These shafts have been connected, at the 400-feet level, by a long drive along the ore-body, and much of the ore has been stoped from this level, practically, and in some cases actually, to the surface. From the ground-level, at the Conrad Shaft, an adit has been driven into the "Big Hill" for about 2000 feet; this is connected with the surface by Moore's Shaft. The mouth of this latter shaft is some 300 feet above that of the Conrad Shaft. The accompanying section (text fig.2) illustrates the positions of the shafts referred to.

The Conrad Lode, like the King Conrad, has a well defined ore-shoot, pitching to the south-east at a steep angle. This is represented by the shaded area in the figure. A very prominent feature of this lode, in which it differs from the King Conrad, is the presence of a conspicuous soft casing or "dig," as it is termed. This occurs sometimes on one, and sometimes on the other side of the fissure. It is always intermediate in position to the lode and the country-rock. It varies from 2 to 9 inches in width, and is of a clayey nature, with abundant quartz-grains similar to those in the granite. The junction of this clay-selvage with the granite-wall is frequently marked by slickensides; and the striæ are vertical in some cases, and horizontal in others. The presence of this soft band is of great economic importance, as it enables mining to be carried on at a minimum cost.

As far as the mineralogical structure of the lode is concerned, it resembles that of the King Conrad. The constituent minerals are the same, consisting of arsenopyrite, pyrite, galena, sphalerite, chalcopyrite, stannite, and quartz. In this lode the stannite, though more abundant than in the King Conrad Lode, is yet only present in small quantity—the tin-content averaging about 0·5 %

of the ore. The silver-values for average ore are higher than in the King Conrad Lode. The silver is probably associated with galena, (possibly as sulphide of silver) but assays show that, of the metalliferous minerals, arsenopyrite and sphalerite also contain appreciable quantities. It was also noticed that, where the galena is associated with sericite, the silver-values are higher; and it is possible that the sericite itself contains silver.

Text-fig.5 is a section of the lode, which is symmetrically banded, and shows the same order of deposition as was noted in the King Conrad Lode. This lode, too, is rather wider than the



Text-fig. 5.—Illustrating the banding of the Conrad Lode.

a, granite—*s*, soft band of kaolinised rock, the "dig"—*b*, arsenopyrite—*c*, sphalerite and chalcopyrite merging into sphalerite and galena—*d*, comb-quartz.

King Conrad, its average width being about 2 feet. This section differs from that of the King Conrad Lode chiefly in the existence of a pronounced "dig," which has been described. The outer bands are of arsenopyrite, and these are followed by admixed sphalerite and chalcopyrite, which pass over into a zone of mixed sphalerite and argentiferous galena. The central portion of the vein is filled with quartz exhibiting well marked comb-structure. It was difficult to select a specimen of sufficiently large size to illustrate the nature of the banding, but Plate xvi., gives a fair representation of portion of the lode. It

is worthy of note that the widest portions of the lode are usually the richest.

The shoot previously mentioned, and represented in text-fig.2, is wider than the normal vein. The latest developmental work in the mine was carried out in prospecting this shoot. Moore's shaft was sunk 150 feet below the main drive, and a winze (marked C in text-fig.2) was put down to the same level, from a spot some distance north, in the main drive. From the bottom of each of these, drives were started to connect with one another. A very interesting and important phenomenon was observed in the drive from the bottom of the winze. After driving for a short distance, it was found that water was entering the drive underfoot. A further examination revealed the fact that the water was proceeding from the clay-selvage. After this, the drive was observed to become hot and stuffy, as well as being continually wet. Unfortunately the temperature of this rising water was not recorded, but the Manager is of the opinion that it was appreciably warm, and that the heat was due to this cause. The foul air was probably due to gases emanating from the water. The amount of water entering the drive was estimated at about 4,000 gallons per day. This drive was under water at the time of my visit. The drive from Moore's shaft did not meet with any such phenomena, and remained cool and fresh throughout.

Another interesting feature in this part of the mine is the abundant replacement of crystallised quartz by zinc-blende. This process has been most active at the spot marked B in text-fig.2. It will be seen that this is close to the place where the water was observed entering the mine from underfoot. The significance of this will be pointed out later.

Three phases in the replacement are well marked :—

The first consists of masses of crystallised quartz in which an occasional crystal of quartz has been partially or wholly replaced by zinc-blende. In this phase, the crystals adjoining the replaced crystal are unaffected by the process(Plate xv. fig.2,A).

The second consists of masses of crystallised quartz, in which many of the crystals have been attacked—some wholly, and others partially replaced by zinc-blende. About one-half of the original material has been attacked in this phase (Plate xv., fig.2,B).

The third consists of masses of zinc-blende, most, if not all, of which has replaced the crystallised quartz. There still remain, strangely enough, odd crystals of quartz which have quite preserved their integrity, though completely surrounded by zinc-blende(Plate xv., fig.2,C).

These facts have suggested to me that, in metasomatic changes, the molecular structure of the crystals plays a very important part. It would appear that a complete crystal may preserve its integrity even where a wholesale metasomatic change is taking place, and yet, as in the first phase, another crystal may entirely break down in the midst of a resisting body of crystals. This has suggested, further, that if, by some means, a portion of a complete crystal be destroyed, the remaining part is in a state of unstable equilibrium, and is thus much more readily attacked than a complete crystal. This might be explained by supposing that each molecule is less strongly attached to the crystal by the attractive forces of its fellow-molecules on a fractured surface, than when in a complete crystal. This may also explain the readiness with which metasomatic processes, in general, operate along cracks in various minerals, as sericite after quartz, etc.

Galena was also found crystallised in the quartz in juxtaposition to the metasomatic zinc-blende, but no definite evidence could be obtained to indicate that it was a metasomatic product. It is probable, however, that such is the case.

At various places throughout the mine, numerous vughs occur. These are lined with large quartz-crystals projecting inwards towards the centre of the cavities. The vughs vary in size from a few inches to several feet in diameter; and are generally bean-shaped, and have their long axes vertical. It is worthy of note that these cavities frequently contain hydrous iron-oxides.

An occurrence which is quite rare in the mine, is the presence of molybdenite. A small piece of that mineral, about the size of a shilling, was found on the north side of the Conrad Lode, at its junction with the King Conrad Lode. There is no evidence of cassiterite or allied minerals in connection with this discovery. Small pieces of molybdenite were also found in the adit-level, and in the 100-feet level, at the Conrad Shaft. The wall-rock bounding the Conrad Lode has not been altered to any great extent. It has been impregnated for a few inches, chiefly with arsenical pyrites and sericite, but the change is not very marked.

The Genesis of the Deposits.

It has been shown that, though the bearing of the King Conrad Lode corresponds to a well marked fissure-system in the Tingha area, some ten miles to the east, yet that of the Conrad Lode is quite unique in direction. It is well established that the tin-deposits are due to the ascent of heated vapours and liquids along lines of fracture; and hence, had the Conrad fissure been in existence at the time of the formation of the tin-bearing veins, it is inconceivable that it could have escaped alteration by the tin-bearing solutions. Hence it is fair to assume that this important fissure is younger than the tin-veins.

Again, it is probable that the King Conrad fissure was initiated contemporaneously with the corresponding set of fractures in the Tingha area, but that it remained closed until crossed by the heavier Conrad fissure, for it would appear that both lodes have been formed simultaneously. It has been mentioned that the Conrad Lode lies at the margin of a large tin-bearing district, and this must not be overlooked in considering the origin of the deposits.

The occurrence of cassiterite in association with metallic sulphides is by no means uncommon. In a previous paper,* I have mentioned several instances; and these I would here recapitulate, in order to trace a connection between tin-veins proper and silver-lead veins.

*Loc. cit.

There occur in the Tingha District—

A.(1) Tin-veins proper—with no metallic sulphides.

(2) Tin-molybdenite veins.

(3) Tin-arsenopyrite veins.

B.(4) Tin-copper-arsenopyrite veins.

(5) Tin-copper-galena veins.

C.(6) Tin-silver-galena-zincblende-copper-arsenopyrite veins.

These six types fall into three groups—

A.Tin as oxide in association with oxides.

B.Tin as oxide in association with sulphides.

C.Tin as sulphide (stannite) in association with sulphides.

Thus a complete gradation can be traced from tin-veins proper to lead-veins in this district. This, then, indicates a common origin for both types of veins. In this connection it is interesting to compare the Conrad Mine with other silver-lead mines in different parts of the world.

Professor Vogt* has written an interesting summary on this point which reads as follows :—"For the older as well as the younger ones [mineral veins], we may declare that a clear genetic connection with eruptive rocks can be established. In some eruptive districts the latest eruptives of the series exposed are even later than the ore-veins; hence the formation of the latter must have occurred during the eruptive epoch."

"Partly for this reason, and partly because of the fact that, on the whole, the veins are generally independent of the petrographic nature of the country-rock, I think we are warranted, in this department also, in assuming, as a working-hypothesis, that the ore-material was extracted from a magma. With regard to the younger veins especially, we must keep in mind a possible extraction from a laccolitic magma in depth."

"In support of this hypothesis, we may cite the transitional, or intermediate occurrences between the cassiterite- and the silver-lead-veins. Thus, in Cornwall, the tin-, tin-copper- and

* Vogt, J. H. L., "Problems in the Geology of Ore-Deposits." Trans. Amer. Inst. Min. Eng., Posepney Vol. 1901, pp. 656-7.

the galena-veins are so closely related topographically and geologically that a common origin must be assumed for them. The same is true of the cassiterite veins and the various silver-lead-ore-formations of the *Erzgebirge*; and the peculiar tin-bearing silver-lead veins of Bolivia may be recalled in this connection."

"These intermediate groups warrant the conclusion that there can have been no absolute essential difference between the genesis of the cassiterite- and that of the silver-lead-veins. If the tin-veins are to be explained by magmatic extraction, the silver-lead veins may not be attributable to the work of underground water."

Again, Spurr,* in considering the sequence of ore-deposition, has summarised his views as follows :—

"In an earlier paper† setting forth a theory of ore-deposition it was proposed by the writer that the most important class of ore-deposits (save of the most common metals) were differentiation-products resulting from the siliceous extreme of the differentiation of rock-magmas; that the successive steps of this metal-depositing stage of the differentiation followed one another in a normal regular order, and were deposited in successive zones, according to temperature. It was also pointed out that, with the downward progress of the cooling of the parent magma (and the consequent sinking of the isogeotherms), the successive zones of mineralization would migrate downward, and successive cementations of successive openings at a single horizon would show the superposition of one zone upon another originally distinctly lower."

"A preliminary attempt was also made to define some of the principal zones as follows :—

"1. The pegmatite zone, containing tin, molybdenum, tungsten, etc., with characteristic gangue minerals, such as tourmaline topaz, muscovite, beryl, etc.

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* Spurr, J. E., "Ore-Deposition at Aspen, Colorado." Econ. Geol. Vol. iv., No.4, June, 1909, p.318.

† Econ. Geol. Vol.ii., No.8, December, 1907, pp.781-795.

"2. The free gold-auriferous pyrite zone, with coarse quartz gangue.

"3. The cupriferous pyrite zone.

"4. The galena-blende (galena usually argentiferous) zone.

"5. The zone of silver and also much gold, usually associated with metals which combine with them to make substances which are undoubtedly highly mobile, and account for the relatively elevated position of the zone. These associated metals include antimony, bismuth, arsenic, tellurium, and selenium. Characteristic minerals of this zone are tellurides, argentiferous tetrahedrite and tennantite, polybasite, stephanite, and argentite.

"6. The zone of earthy gangues, barren of valuable metals."

Here we see that the order which he ascribes to ore-formation from magmatic differentiation is, (1) tin and allied ores, (2) free gold-auriferous pyrite zone, (3) cupriferous pyrite zone, (4) galena-blende zone.

In connection with the Borah Creek Mine, it has been shown—

1. The Mine is situated in the same country-rock (the "acid granite") as the adjacent tin-deposits.

2. Arsenopyrite is the earliest deposited mineral in the lode.

3. This is followed by a sphalerite-chalcopyrite zone.

4. And further by a galena-zone (argentiferous).

5. And finally by a quartz-filling.

The order of deposition in the Borah Creek Mine, and its association with the tin-deposits, is thus strikingly in accord with the generalised order suggested by Mr. Spurr.

The arguments in favour of the formation of the Borah Creek Lode from a deep-seated, magmatic extraction are briefly as follows:—

1. The relationship of the deposits to the adjacent tin-deposits —a complete gradation existing between the two types. This relationship is not unique, but occurs in other parts of the world.

2. The absence of ore in the joints adjacent to the lode is evidence against the lateral secretion theory.

3. The compact nature of the country-rock is also against the lateral secretion theory.

4. The great length (more than a mile), and the great uniformity in both length and breadth, are not favourable to the lateral secretion theory.

5. The presence of ascending warm water is in favour of a deep-seated origin.

6. The presence of stannite, which could not have been formed from meteoric waters by any known chemical reactions.

Sequence of Processes involved in the Formation of the Ore-Body.

The following is put forth as an explanation of the Borah Creek ore-deposits.

In or about Permian times, the shales in this portion of New England were intruded, first by a biotite granite, and later by the "acid granite." As this last intrusion solidified, it cooled from above downwards, thus forcing the unsolidified portions of the magma—largely silico-aqueous solutions of minerals—to a greater depth in the earth's crust. The contraction of the mass, consequent in cooling, gave rise to strains which were relieved by systems of fracture, more or less constant in direction, along which the aqueous mineral-bearing solutions were able to rise.

It has been pointed out that there were two eras of fracture at Borah Creek, one contemporaneous with the fractures of the Tingha tin-district, and the other postdating the formation of these ore-deposits. The earlier fracture remained closed until the development of the later one. The later fissure is, by far, the more important, and its formation was attended by the development of a crushed zone along the line of fissure. Solutions arising along this crushed zone, attacked the felspars, and effected complete kaolinisation. Following this kaolinisation, further movement occurred, giving rise to slickensides on the walls of the crushed zone. The movement was predominantly vertical in some parts, and horizontal in other parts of the mine. Next came the opening of the fissure, which gave a more ready access to the solutions. In the course of this opening, the crushed zone adhered, for the most part, either to one wall or

the other, but occasionally divided, and adhered, in part, to both walls. This opened the way for the deposition of the ores. Previously the solutions arising along the crushed zone were slow-moving, and chilled rapidly with ascent, thus losing, at the same time, their solvent power. With an open fissure, however, the ascending solutions could maintain a relatively high temperature, and so carry the metallic substances towards the surface. When the temperature fell, the most insoluble minerals, under the conditions of solution, were naturally the first to precipitate.

Change in the nature of the solution, due to minerals precipitated from it and access of new solution, doubtless complicates the problem, but several well marked phases of deposition may, nevertheless, be distinguished. Arsenopyrite is found forming as the outside zone, and is, consequently, the earliest deposited mineral. It is, as a rule, fairly well marked-off from the sphalerite band, which lies adjacent to it on either side of the lode. In many places, a good deal of pyrite is associated with the arsenopyrite, and seems to be partly later, and partly of contemporaneous origin Following the deposition of sphalerite, came the formation of admixed copper pyrites and sphalerite. Accompanying this phase of the deposition, stannite is to be found in the vein. This mineral does not usually occur as a distinct band or vein,* but in bunches of irregular shape and size, situated between the zone of sphalerite and the inner metallic zone, which is galena. The last deposition filled the centre of the fissure with comb-quartz.

The presence of numerous vughs in the mine, with their linings of quartz-crystals, and occasional fillings of hydrous iron-oxides, suggests the following explanation. As the fissure became filled by deposition from solution, some irregularity in the filling might well be conceived; and, hence, the possibility of certain spaces being cut off from the main body of solution, may be readily admitted. Given an isolated body of solution, crystallisation

* In one place stannite was observed as a very distinct band in the lode. In this case, it occupied a position between the arsenopyrite and sphalerite bands.

would proceed, with fall of temperature; and, according to the observed order in the fissure-filling, quartz should be the last constituent to crystallise; and this is found to be the case in the vughs.

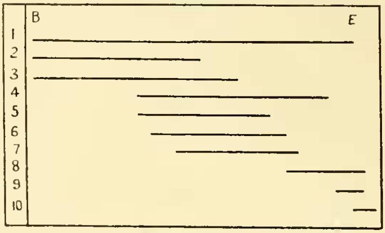
Though the order given above is typical of the mine in general, it frequently happens that one of the zones of mineral is repeated in the series, *e.g.*, the arsenopyrite band in the centre(text-fig.4). Again, quartz is always more or less present throughout the whole width of the vein-stuff, being intergrown with all of the minerals occurring in the mine. The irregularity in deposition of the metalliferous zones may be ascribed to a pulsating movement in the solution, so that a solution which has already deposited, say, a layer of zinc-blende, may, by decrease in pressure, be caused to sink in the fissure, and become diffused in the bulk of the solution; thus, when the fissure was again charged with solution, arsenopyrite would probably be again deposited, and the cycle of deposition be re-established. A diagram has been drawn to indicate the relative order of crystallisation(text-fig.7).

After the complete filling of the lode, further earth-movements resulted in fractures trending about N.15°W., and S.15°E. These have intersected both the King Conrad Lode and the Conrad Lode(text-fig.1). The faults intersecting the King Conrad are due to minor movements, but that throwing the Conrad Lode is on a larger scale. No deposition has taken place along any of the fault-planes.

Correlation with other Occurrences.

Mr. Spurr, in examining the ore-deposits of Monte Cristo, has tabulated some very interesting observations on the order of deposition of the ores in that district. He points out that, in this mine, metasomatic changes have been so great that, except in local crustified portions of the lode, it is difficult to make out the sequence of crystallisation. In the Conrad Mine, on the other hand, the lode is typically well banded, and the problem is comparatively easy of solution. As has been pointed out, metasomatic action has not played an important part in the Conrad Lode, being represented only by changes in the lode-material, and

slight alteration of the walls of the lode. In his examination of the ore-deposits of Monte Cristo,* Mr. Spurr has given an ideal diagram of the sequence of the ores in this district. This is here reproduced (text-fig. 6), slightly modified, for comparison with the order observed in the Borah Creek Mine. A corresponding diagram (text fig. 7) has been drawn for the sequence of ore-deposition in the Borah Creek Lodes. There is a very striking similarity between the structure of the two ore-bodies.

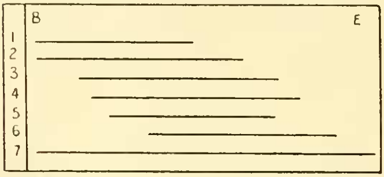


Text-fig. 6—Modification of Mr. J. E. Spurr's diagram illustrating sequence of ore-deposition at Monte Cristo, Washington.

B, Beginning of crystallisation—E, End of crystallisation—1, quartz—2, arsenopyrite—3, pyrite—4, chalcopyrite—5, pyrrhotite—6, blende—7, galena—8, realgar—9, stibnite—10, calcite.

Summary.

The Borah Creek Mine is situated in the New England District of New South Wales, within two miles of the Gwydir River. The lode is a solid granite, of a very acid nature, which has intruded an older and more basic granite. The "acid granite," as Mr. Andrews has termed it, has been shown by several writers to be intimately related to the tin-deposits occurring along its margin. The Borah Creek Lode crosses the contact



Text-fig. 7. — Diagram illustrating sequence of ore-deposition at Borah Creek.

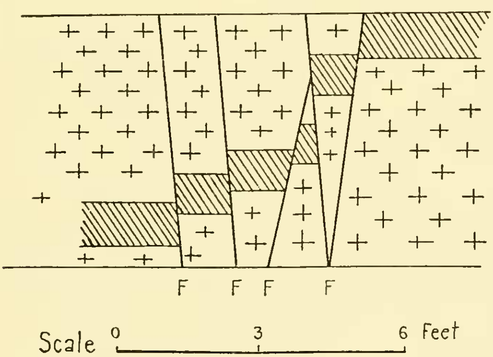
B, Beginning of crystallisation—E, End of crystallisation—1, arsenopyrite — 2, pyrite—3, chalcopyrite—4, sphalerite—5, stannite—6, galena—7, quartz.

* Spurr, J. E., "Ore-deposits of Monte Cristo, Washington, Twenty-Second Annual Report U.S. Geol. Surv., Pt.ii., Ore-deposits, p.840.

of the "acid granite" with the older granite, but lies mainly within the former. The age of this "acid granite" has been estimated as Permian.

The ore-deposits occupy two fractures, one trending E.5° N., and the other, and more prominent, trending E.35° S. The former lode is parallel to a well developed series of fractures in the tin-bearing district some ten miles further east; the latter has no representative system of fractures in the district. It is inferred that the Borah Creek deposits are of a younger age than the tin-deposits, for, had such a fracture as the Conrad Lode existed at the time when these were formed, the active processes accompanying their formation would assuredly have affected the fracture.

A series of faults bearing about N.15° W. have intersected both lodes. A pretty example of the minor faulting in the King Conrad Lode is represented in text-fig.8. The only important fault is that intersecting the Conrad Lode. This fault has



Text-fig. 8.—Diagram illustrating faulting in the King Conrad lode. F, fault.

determined the position of several small streams. One of these stream-courses may be noted in text-fig.1, on which the sketch-contours indicate how the fault has influenced the physiography. This may also be seen in Plate xv., fig.1.

The proximity of the lodes to the tin-lodes and their occurrence in the same rock, suggest some relationship. A complete series of types of lodes has been made out, between the tin-veins proper and the complex ore-bodies of the Borah Creek Lodes. The ores contained in the mine are arsenopyrite, zinc-blende, chalcopyrite, stannite, and galena. The ores are the same in both lodes, but rather more stannite is present in the Conrad than in the King Conrad Lode. In the Conrad Lode the clay-selvage is present, sometimes on one side, sometimes on the other, and occasionally on both sides of the lode. This does not occur in the King Conrad Lode. The ores are very uniformly distributed through the mine, both along the lode and in depth. There is practically no oxidised zone and the sulphide ore outcrops in the bed of Borah Creek, the direction of which has been determined by the lode. There are two fairly well defined shoots in the mine, a small one occurring in the King Conrad Lode, and a larger one in the Conrad Lode. These are shown by the shaded areas in text-fig.2.

The order of deposition of the minerals, which form symmetrical zones in the fissure, is arsenopyrite, stannite, pyrite, zinc-blende, chalcopyrite, galena, and finally quartz. This normal order is frequently disturbed by the reopening of the fissure, and also by the rejuvenescence of the depositing solution. The deposit is a very typical, banded fissure-lode, and very little metasomatic replacement occurs, though it was carefully sought for. The country-rock has been feebly altered for a few inches from the lode, the replacing constituents being chiefly arsenopyrite and sericite. Two well-marked examples of replacement of the vein-material were observed. At A in text-fig.2, the galena forming one of the zones in the lode has been replaced by quartz, which has retained to perfection the cleavages of the original mineral. This change has been effected by surface-waters. At B, in the same figure, beautiful examples of replacement of quartz by zinc-blende are abundant. This change has probably been effected by rejuvenated, ascending solutions. In the bottom drive of the mine, at the spot marked D, warm

ascending waters were observed to enter the drive from the clay-selvage. This phenomenon is probably the last phase in the deposition of the ores.

Comparison with other occurrences indicates the probability of a genetic relationship between the silver-lead deposits and the tin-deposits. The tin-deposits of Cornwall, Germany, and Bolivia have been thought to be closely related to the silver-lead deposits in proximity to them. Again, Mr. Spurr has proposed a magmatic extraction theory for ore-deposition, which is strongly supported by the evidence of the sequence of deposition contained in this paper. It is suggested that the Borah Creek deposits have been formed later than the tin-deposits, by deposition from highly aqueous and siliceous magmatic extractions containing relatively large amounts of metallic sulphides.

Conclusion.

In conclusion, it may be said that the genesis of the ore-deposits indicates—

(1) Permanence of the ore-body at much greater depth than the limits of mining can attain.

(2) A gradual increase, with depth, in arsenical pyrites, zinc-blende, and possibly stannite, though, from the uniformity of the lode, as already known, this probably takes place so gradually as not to affect very appreciably the economic value of the deposits.

(3) The probable permanence of the shoot in which the ascending waters were discovered in the Conrad Lode.

It is not too much to hope that, in the near future, the metallurgical difficulties in dealing with so complex an ore may be solved, and that this mine will take rank amongst the most valuable of this State's mineral assets.

EXPLANATION OF PLATES XV.-XVI.

Plate xv.

Fig.1.—Photo. of Borah Creek, showing how the line of lode corresponds with the Creek; and also showing the effect of the large faults upon the topography.

LLL, line of lode - FFF, line of fault—M, Moore's Shaft—D, Davis's Shaft—C, Conrad Shaft—7, winze—5, winze—A, Alwell's Shaft.

Fig.2. —Three specimens illustrating extent of the metasomatic replacement of quartz by sphalerite.

A, massive quartz with one hexagonal crystal, replaced by sphalerite—B, more advanced stage of metasomatic replacement—C, stage of almost complete replacement; only a few quartz crystals unattacked.

(Two-thirds nat. size.)

Plate xvi.

Portion of Conrad Lode illustrating banding.

A, pyrite and chalcopyrite with quartz—B, sphalerite, with quartz-seams—C, galena—D, quartz.

(Two-sevenths nat. size.)

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